Towards understanding the impact of cirrus clouds on troposphere-to-stratosphere transport

Hui Su[1], Jonathan Jiang[1], Xianglei Huang[2], Kenneth Minschwaner[3]

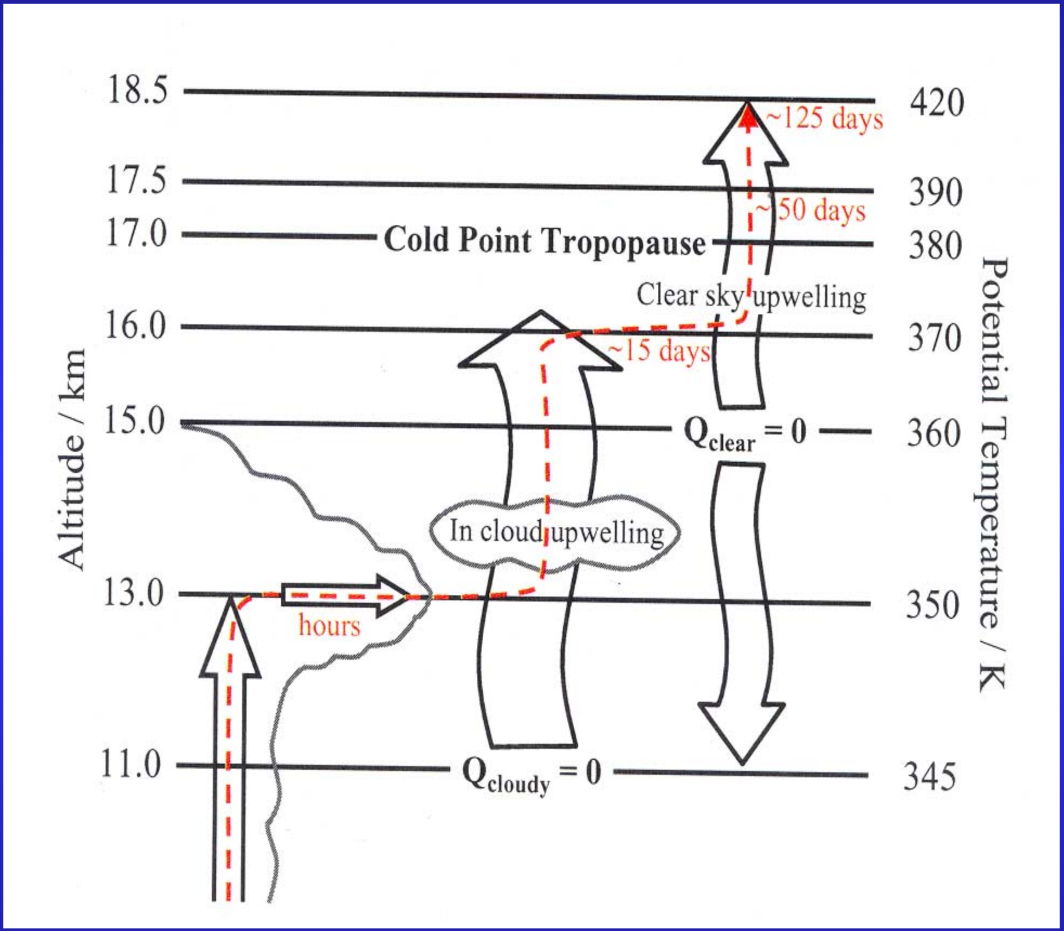
[1]Microwave Atmospheric Science Team, Jet Propulsion Laboratory, California Institute of Technology

[2]Department of Atmospheric, Oceanic, and Space Sciences, University of Michigan

[3]Department of Physics, New Mexico Institute of Mining and Technology

EOS Aura Science Team Meeting, 1-5 October, 2007, Pasadena, CA

Motivation



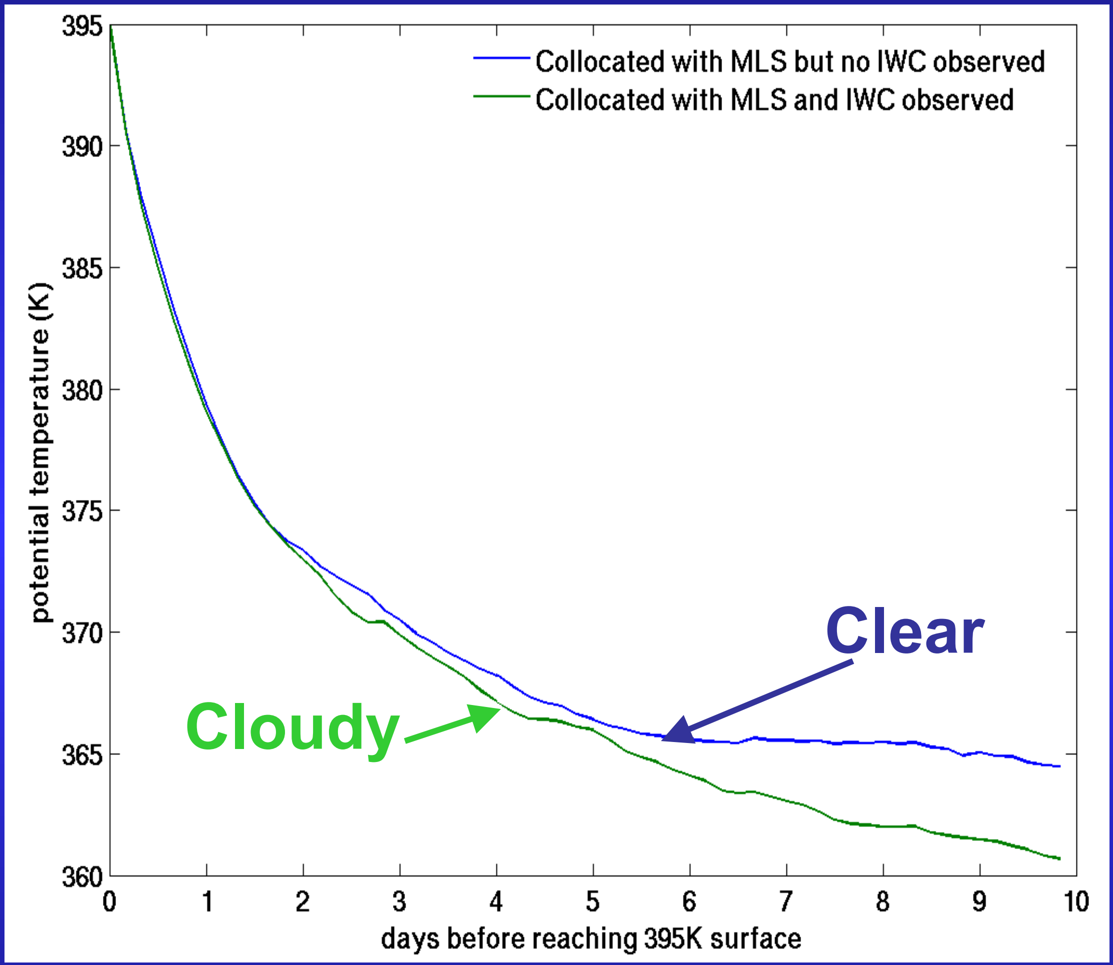
- Cirrus radiative effect provides a faster troposphere-to-stratosphere transport (TST) than clear-sky radiative heating.

- Issues: limited cirrus data (LITE 10-19 September 1994), sparse radiosonde atmospheric profiles, one-dimensional view of transport (tropical-mean condition only)

From Corti et al. 2006

<u>Does this view apply in 3-dimensional reality?</u>

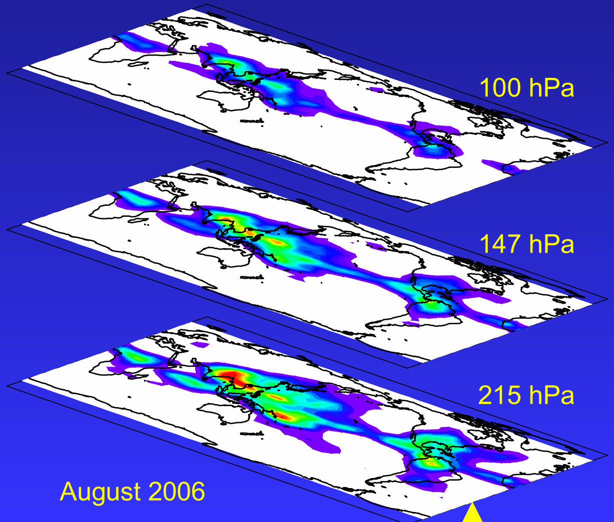
Indication by Trajectory Analysis

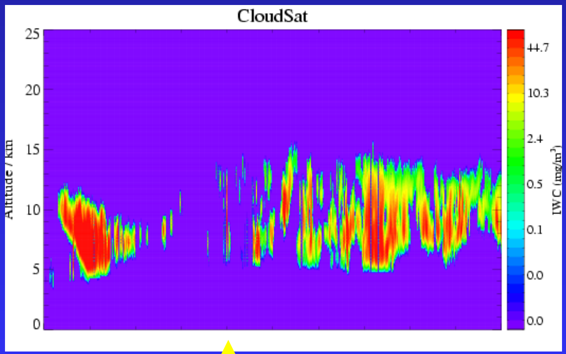


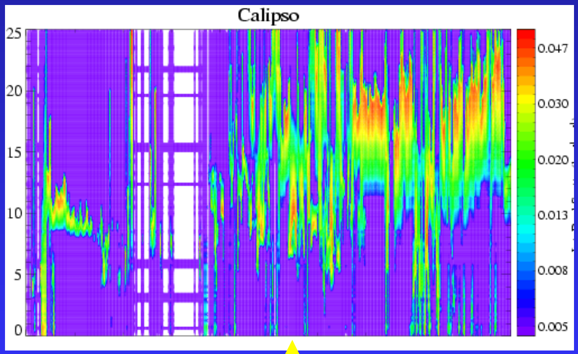
- Use NOAA Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model driven by 6-hourly NCEP winds
- Parcels distributed uniformly between 10°S-10°N in the lower stratosphere between 400 K and 410 K
- 30-day back trajectory starting on 1200UTC, Jan 31, 2005
- Identify parcels passing through TTL (~350 and ~380K) and overlap with MLS observations
- Sort the trajectories by collocated MLS IWC

Parcels passing through clouds ascend faster in the TTL than parcels staying in clear sky

The timely opportunity provided by A-train: synergy from Aura MLS, CloudSat, and CALIPSO



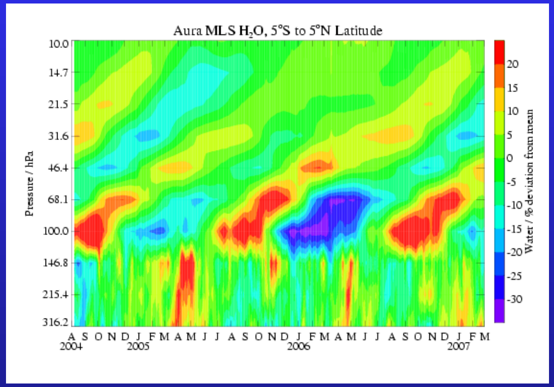


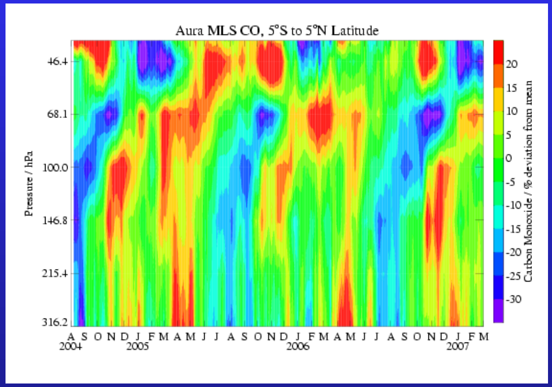


Aura MLS

CloudSat

CALIPSO

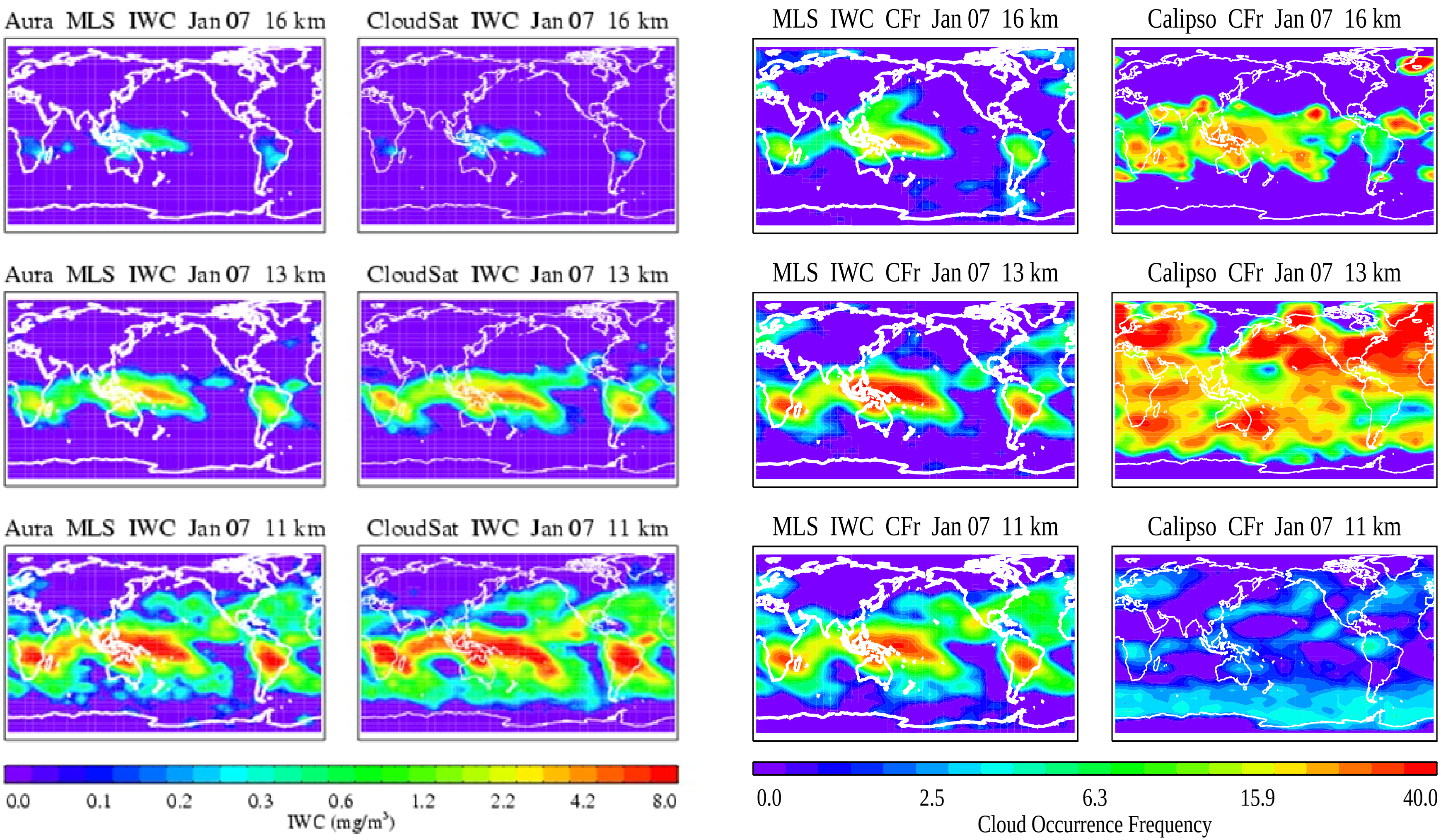




"Tropical tape recorder" seen in Aura MLS H_2O & CO

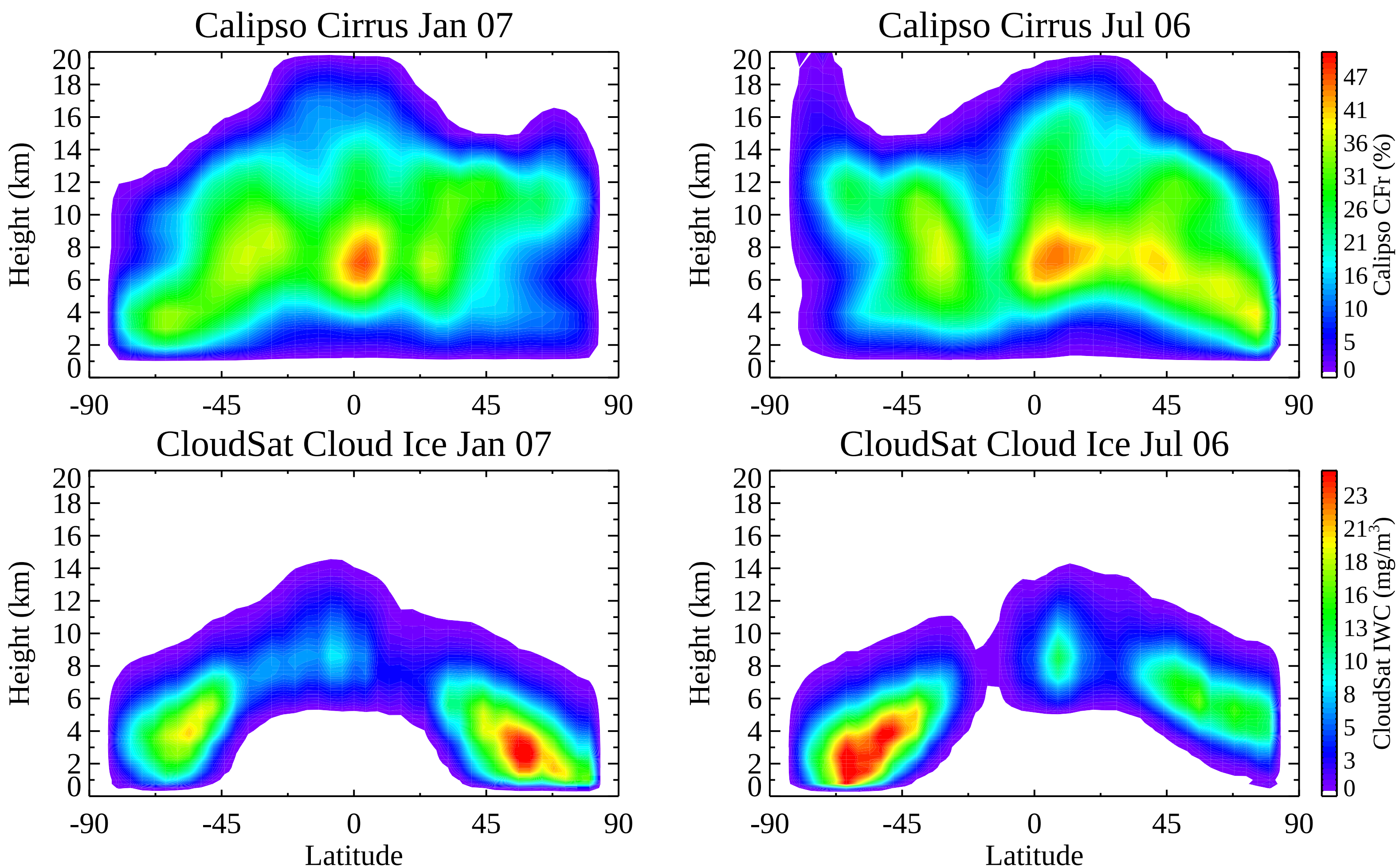
- A-train data provide a best opportunity to study the cloud radiative impact on TST with measurements of global cloud and atmospheric profiles
- Spatially and temporally varying 4-dimensional view of TST pathways can be obtained and the role of clouds can now be better quantified

TTL Cirrus Observed by Aura MLS, CloudSat and CALIPSO



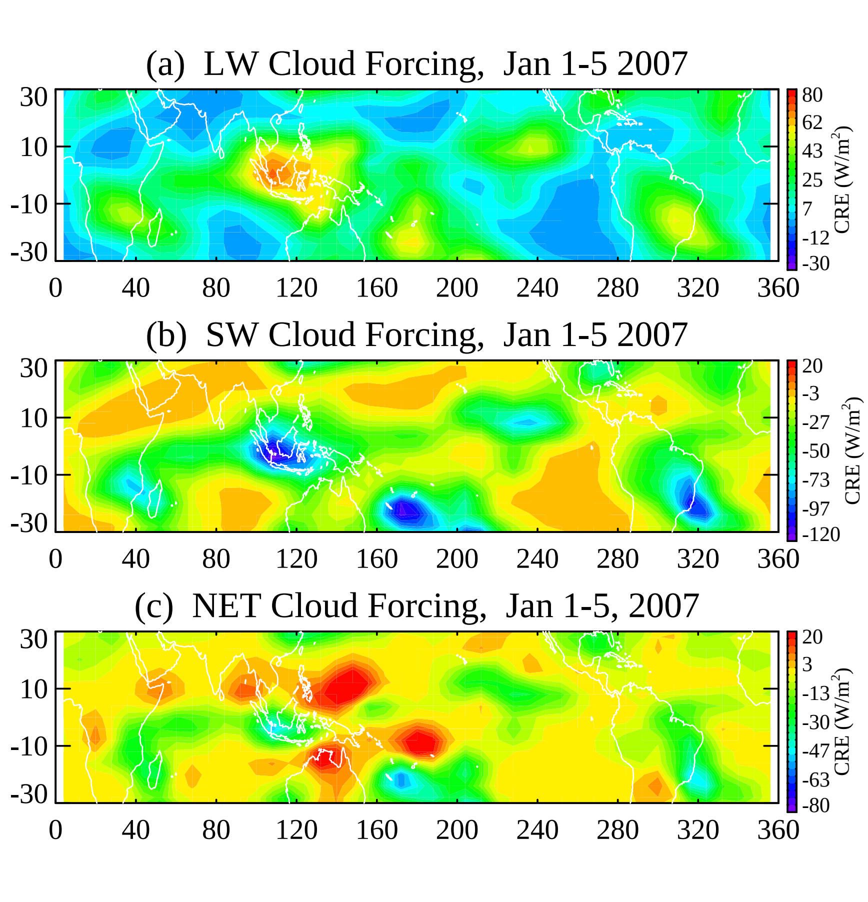
Aura MLS, CloudSat, CALIPSO have different sensitivity to the TTL cirrus. Careful data fusion is needed to best represent the TTL cirrus properties.

CloudSat/CALIPSO Zonal Mean Cloud Profiles

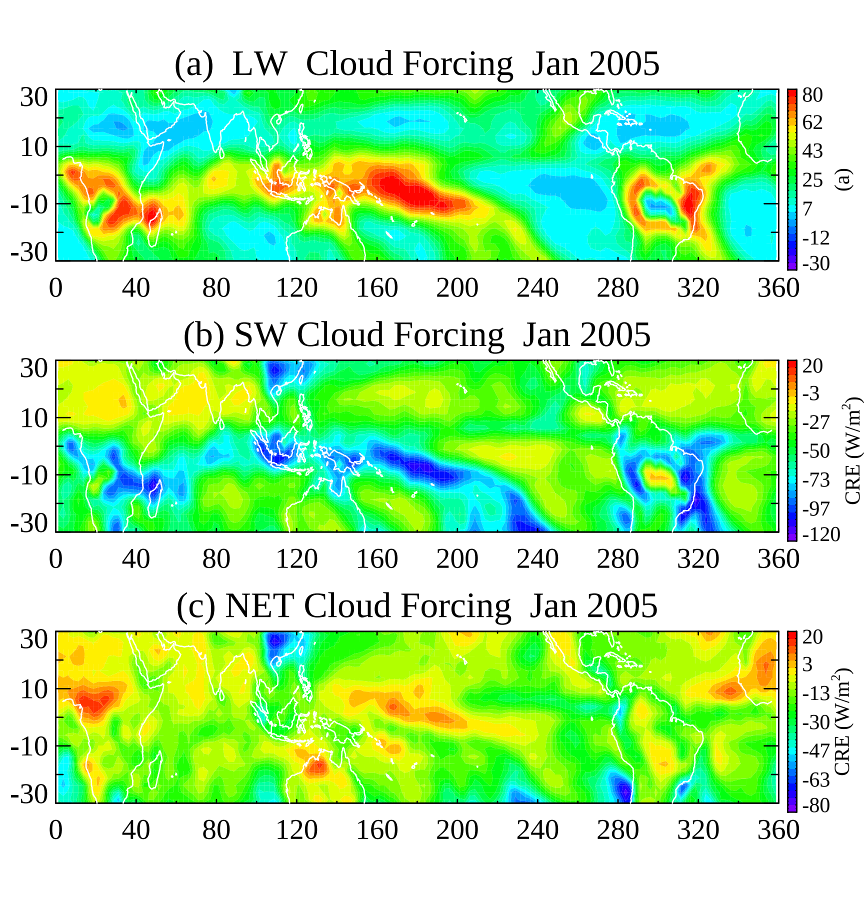


Preliminary Radiation Calculations Using CloudSat

CloudSat

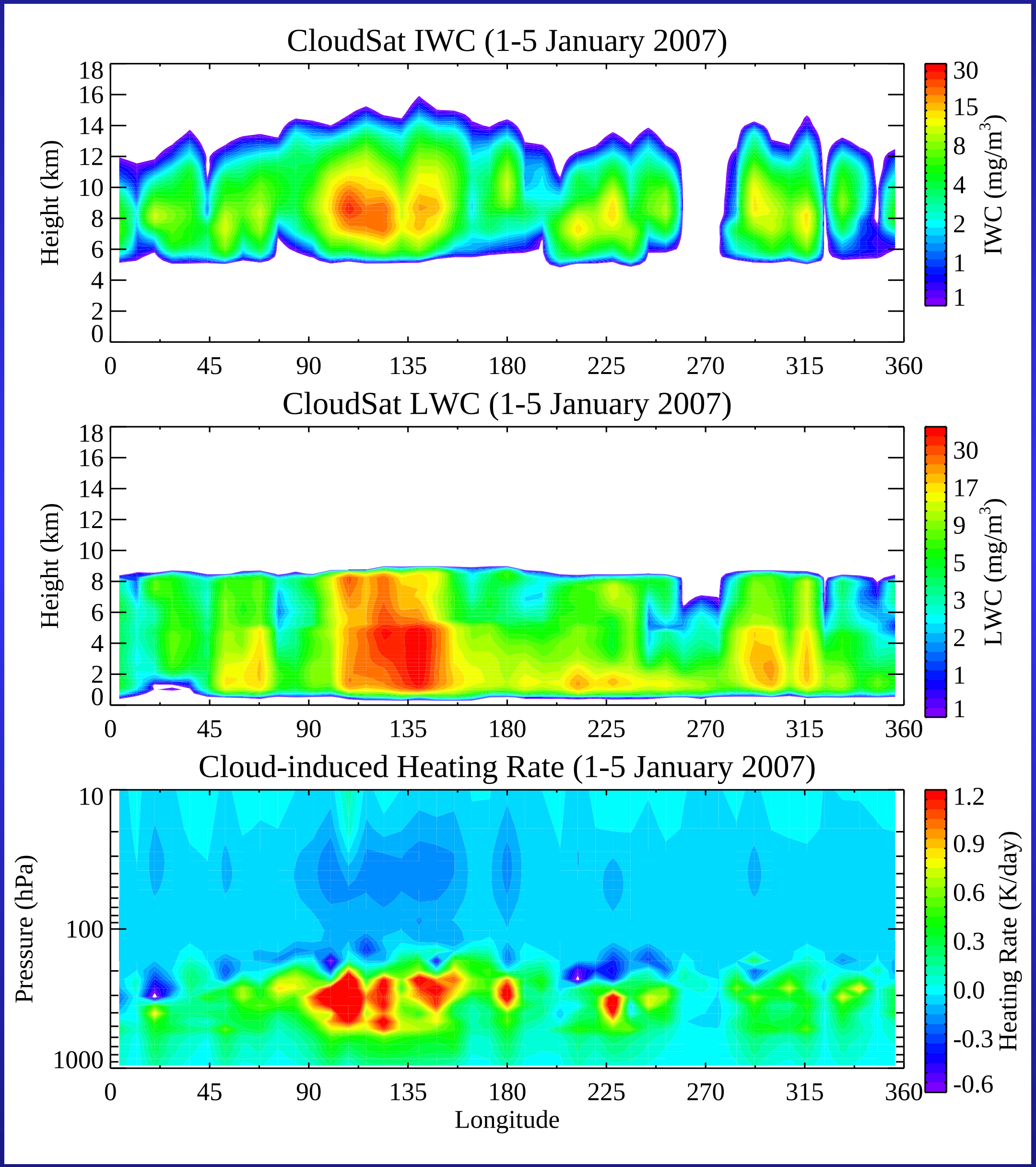


CERES



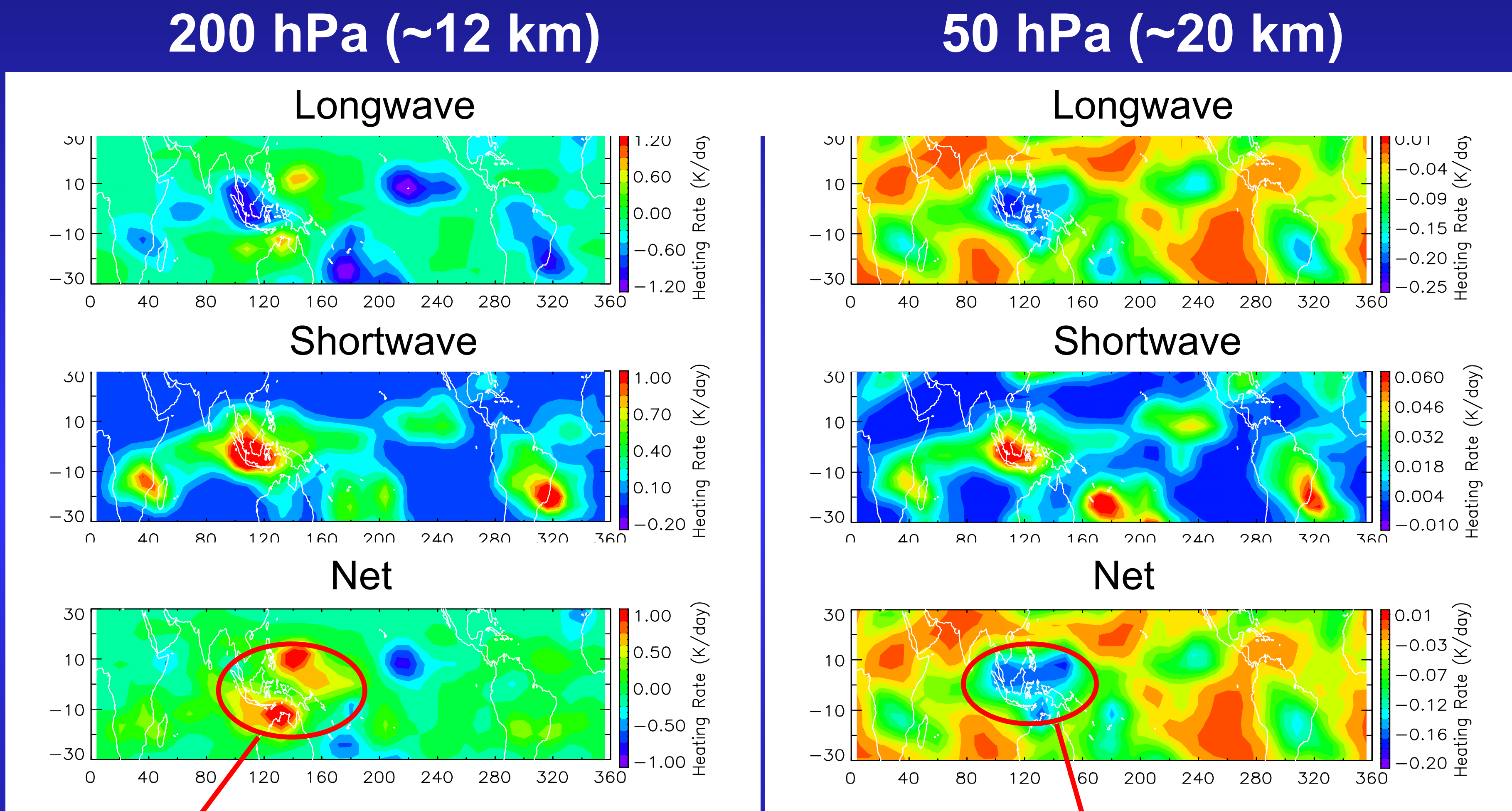
- Calculated top-of-atmosphere longwave and shortwave cloud forcing using CloudSat IWC/LWC is weaker than the respective observed cloud forcing by CERES, but the net cloud forcing is larger than CERES. Differences may be due to cloud particle size assumption, observed atmospheric profiles, and different time period, etc.

Cloud-induced Radiative Heating Rate Profiles



- In the troposphere, cloud-induced radiative heating is more than 1 K/day.
- In the upper troposphere and the base of TTL, the cloud-induced radiative heating is less than 1 K/day. Radiative cooling also exists.
- In the lower stratosphere, cloud-induced radiative cooling is about –0.2 K/day, with the minimum over the western Pacific maritime continent between 30-70 hPa.

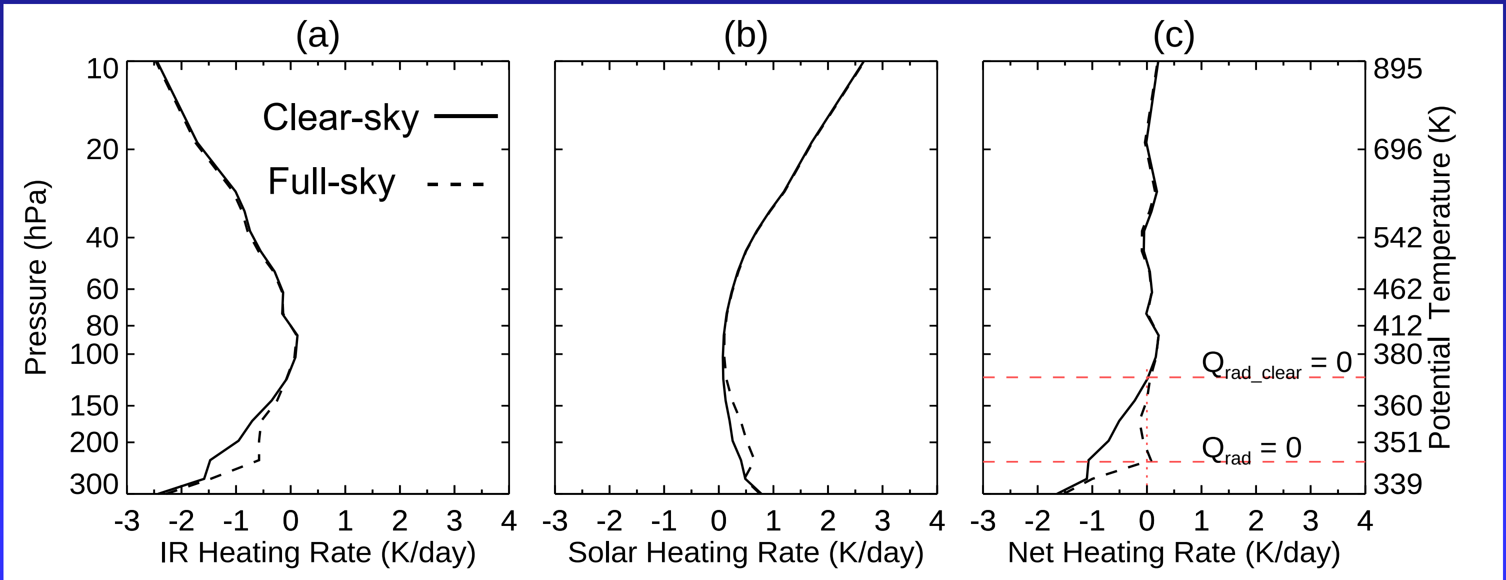
Cloud-induced Radiative Heating Rates



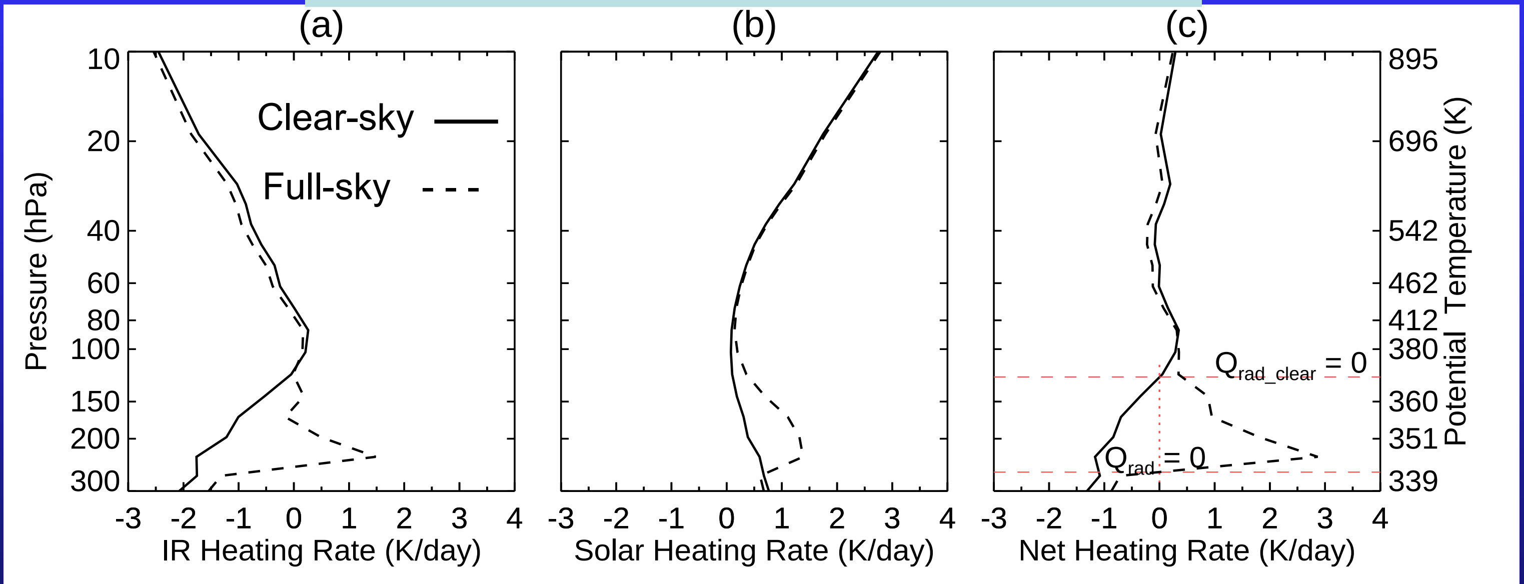
- Cloud-induced radiative *heating* in the upper troposphere can provide a faster ascending rate for the TTL mass transport.
- Cloud-induced radiative *cooling* in the lower stratosphere may partly contribute to the diabatic descent over the maritime continent - - - → "Stratospheric Drain".

Radiative Heating Rates Using MLS

Tropical-mean (30ºS-30ºN)



Western Pacific (120ºE-180º, 30ºS-30ºN)



Conclusions

- Initial trajectory analysis indicates that in-cloud upwelling in the TTL can be faster than the clear-sky upwelling .

- Preliminary radiative heating calculations using CloudSat data show that clouds induce radiative heating at the base of the TTL. The amplitude of local heating rates is up to 1 K/day. This rate may be underestimated due to missing thin cirrus by CloudSat.

- Cloud-induced radiative cooling is found in the TTL, which may have implications for dehydration of water vapor entering stratosphere.

- In the lower stratosphere, cloud-induced radiative cooling maximizes over the maritime continent, partly contributing to the descent for the “stratospheric drain”.

Future Work

1. **Combine A-train data to compute radiative heating rates**
   > cloud profiles from MLS/CloudSat/CALIPSO
   > atmospheric profiles from Aura MLS and Aqua AIRS

2. **Use a two-column model with the computed heating rate as input to delineate cirrus radiative impact on UT/LS tracer distributions, and compare with Aura MLS tracer (H_2O, O_3, CO, HNO_3) observations**

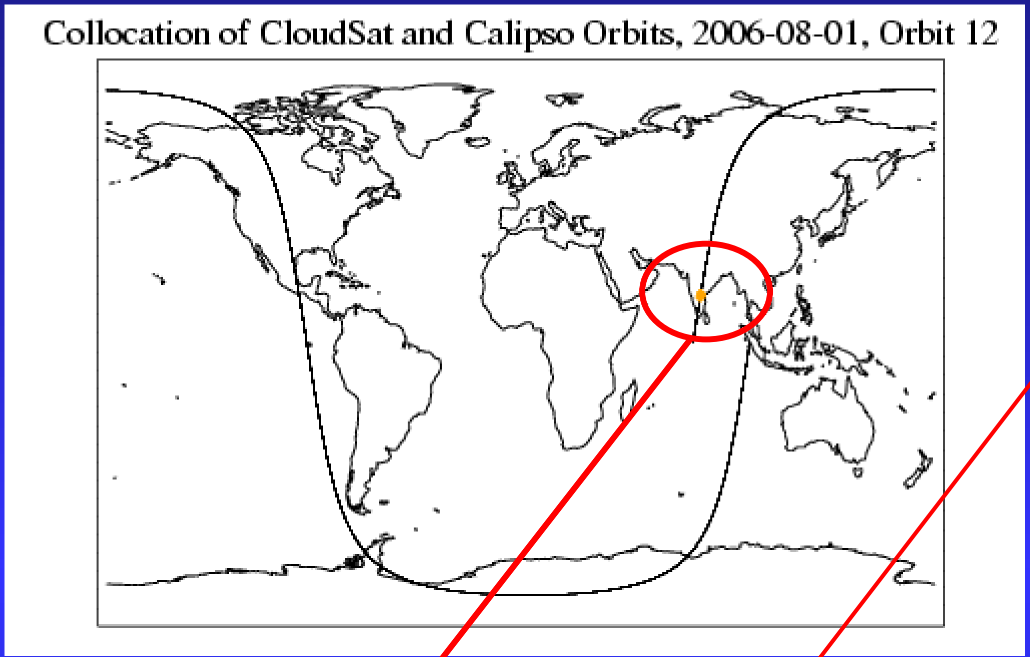
$$M_{rad} = \rho w_{rad} = \rho Q_{rad} / \sigma$$

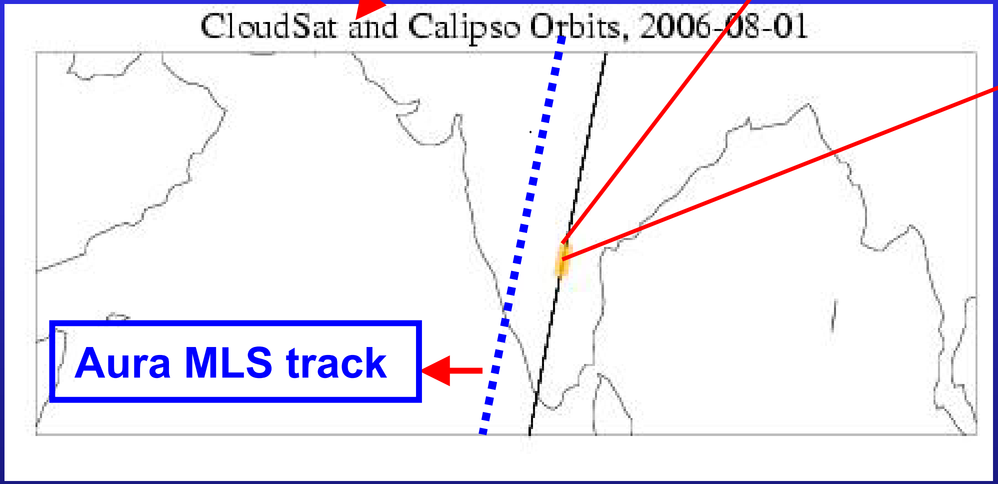
$$\frac{\partial [X]}{\partial t} = \frac{dM_{rad}}{dz}([X]_c - [X]) + M_{rad}\frac{d[X]}{dz} + P - L$$

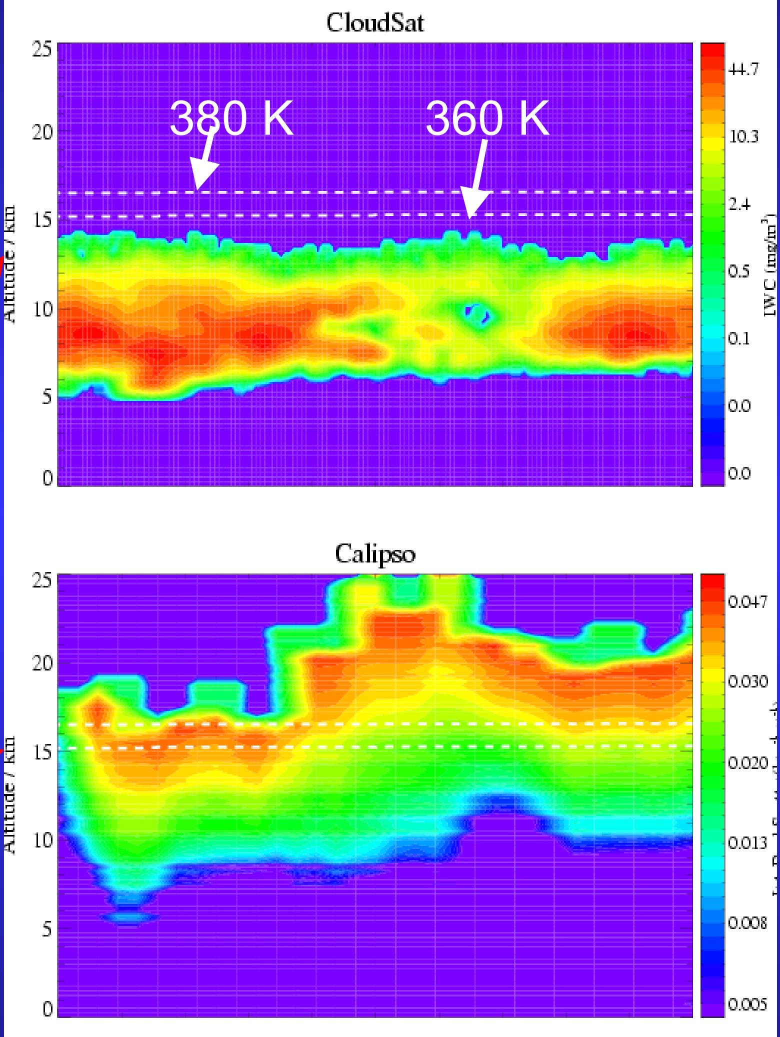
3. **Drive the trajectory model with clear-sky and all-sky radiative heating rates to quantify how clouds modify the mass transport between troposphere and stratosphere**

Back-up Slides

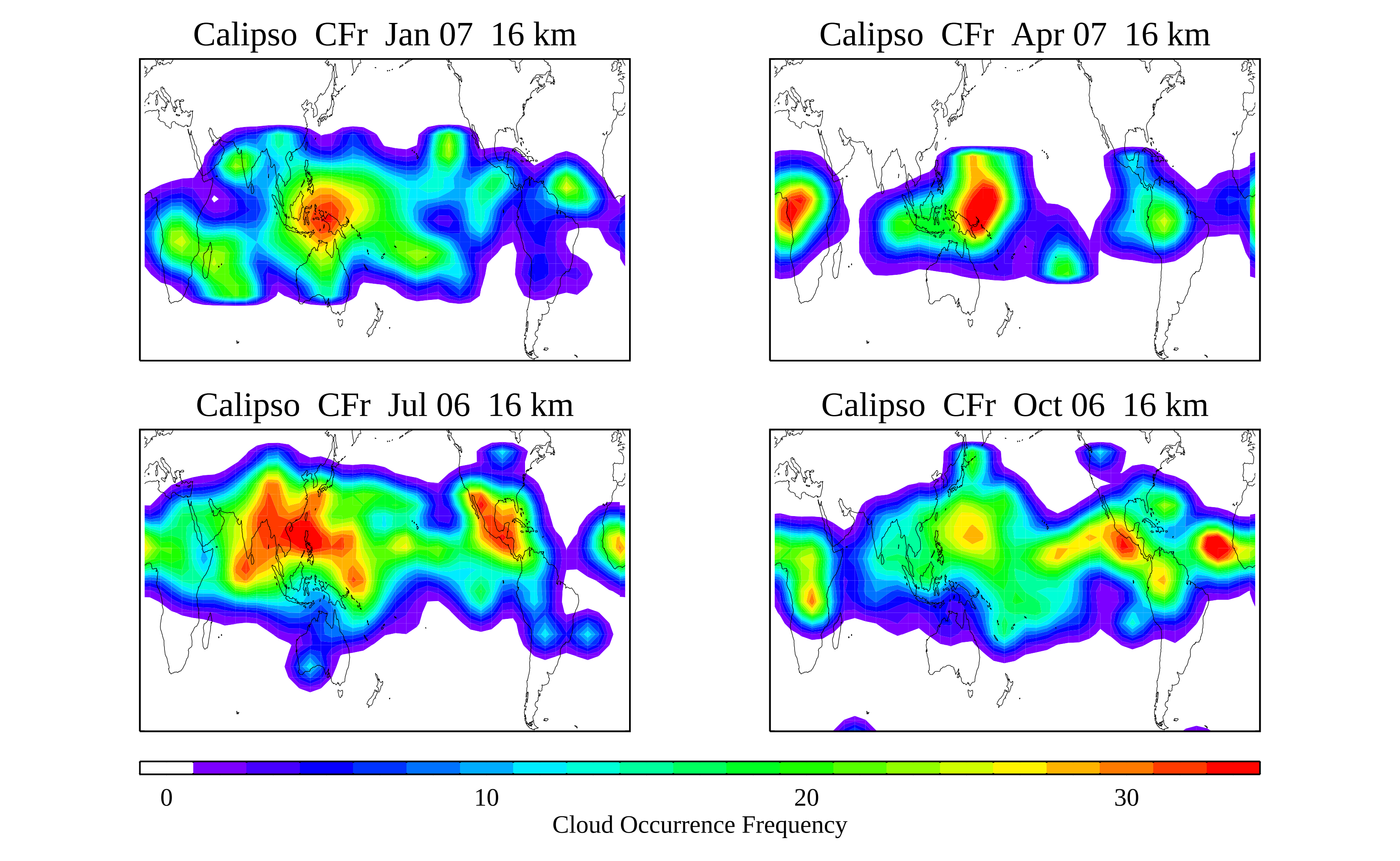
Combine Data on Orbit Tracks



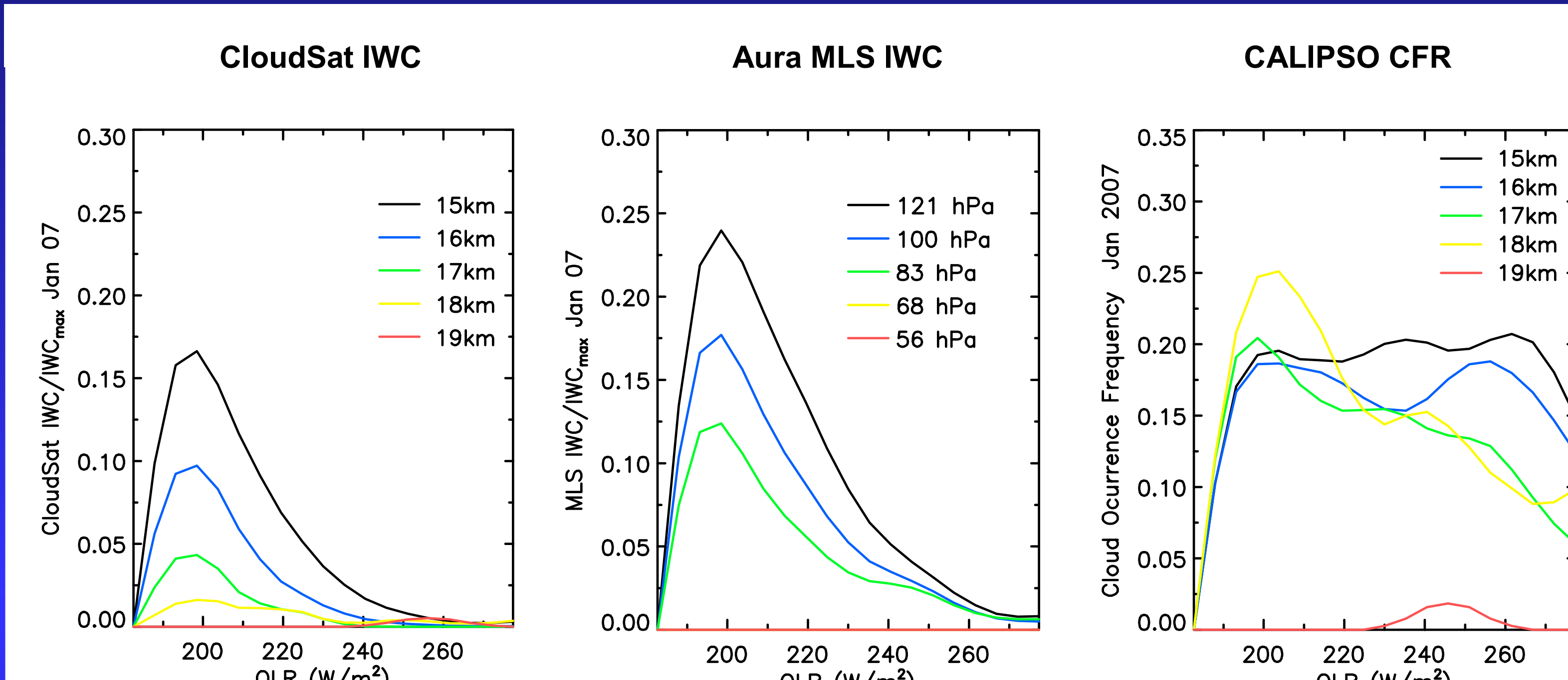




Seasonal Variation of CALIPSO Cirrus



Relation with Deep Convection



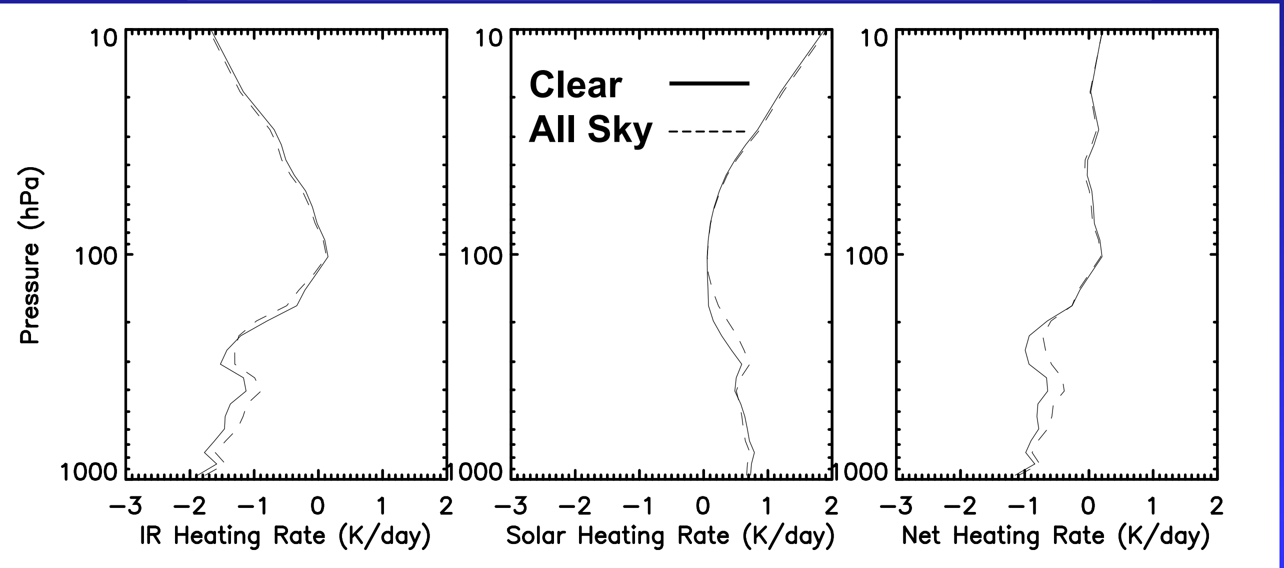
CloudSat and MLS IWC in the TTL are distributed mostly near low OLR (deep convection) regions, while CALIPSO cirrus spread over a wide range of OLR. Higher cirrus are more co-located with convective regions.

CALIPSO observed cirrus occurrence frequency is not linearly correlated with local temperature. From 15 km to 18 km, there is a tendency of more cirrus associated with colder temperature. The cold temperature is generally coupled with deep convection.

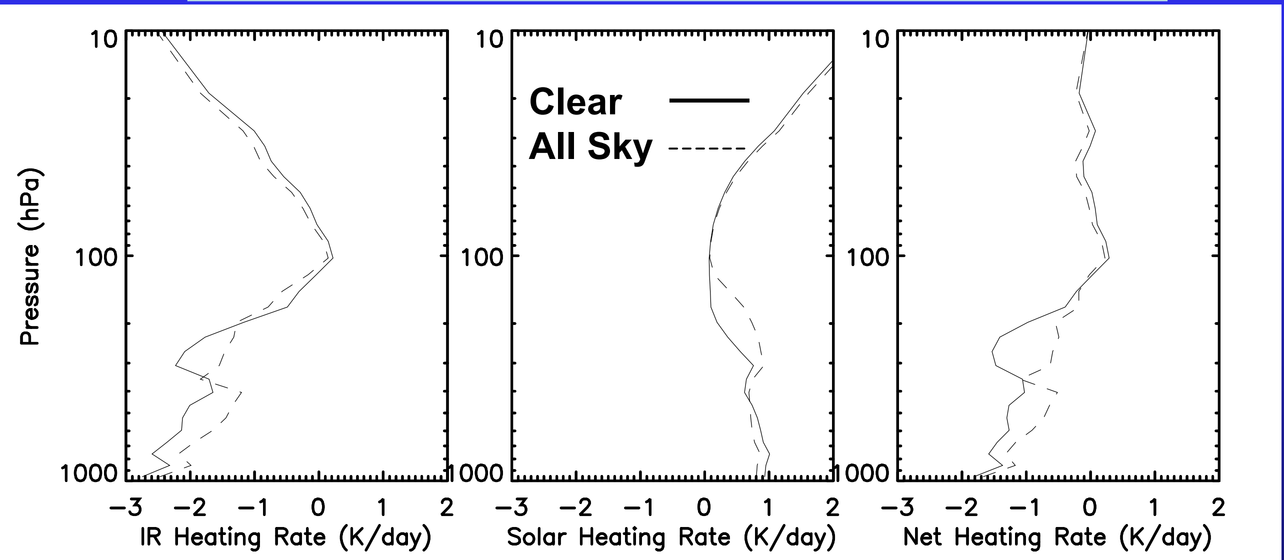
CALIPSO CFR

Radiative Heating Rate Profiles Using CloudSat Data

Tropical-mean (30ºS-30ºN)



Western Pacific (120ºE-180º, 30ºS-30ºN)



- Tropical-mean cloud-induced heating rate is less than 1 K/day in the TTL, although cloud-induced heating rates over deep convective regions can be a few times larger.
- Clouds produce net radiative cooling from 100 hPa to 30 hPa, about –0.2 K/day.